

**NuTRoNS 1: Nucleonica Training Course on Nuclear Science**  
**Joint EC / IAEA Monaco Nuclear Science Training Course**  
**12 - 15 October 2010, Monaco**

# **Introduction to the Gamma Spectrum Generator**

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[www.nucleonica.net](http://www.nucleonica.net)

**nucleonica** 

Nucleonica - Gamma Spectrum Generator - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.nucleonica.net/Application/Spectrum/Spectrum.aspx

Most Visited Getting Started Latest Headlines Windows Media Windows Бесплатная почта H... Настройка ссылок

Nucleonica - Gamma Spectrum Gene...

nucleonica ... web driven nuclear science

Applications Data Knowledge My Preferences Print Help New Browser

Getting started  
Reference manual

Questions, remarks, suggestions  
can be posted in the [forum](#)

Co60  
10.47 m 5.27 y

**Gamma Spectrum Generator**  
**27 Cobalt**

Actual chart: Karlsruhe

Element: Co Mass: 60 Nuclide Mixtures Selector

Quantity: Bequerel Reference point: 1000000 Measurement start

Measurement setup Calculation results Options

Measurement time: sec 1000 Start Start in background

Current configuration: NaI, L x D = 3 in x 3 in (default) Save as Delete

Dimensions in mm

Source

Filter

Crystal

Crystal diameter 76.2

Source to Detector distance 250.0

Crystal length 76.2

Show more settings

Done

How to get to the GSG page:

1. Choose Applications-  
>Gamma Spectrum Generator  
from the Nucleonica's main  
menu

OR

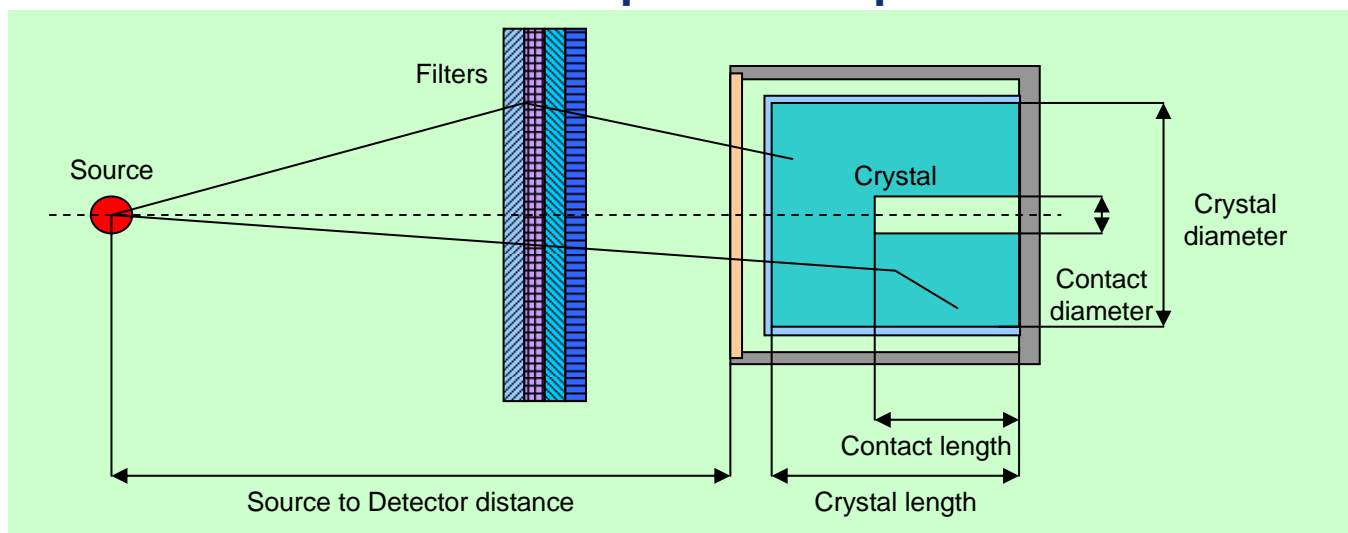
2. Go to the Nuclear Science  
Applications Portal and select  
Gamma Spectrum Generator  
from the application list



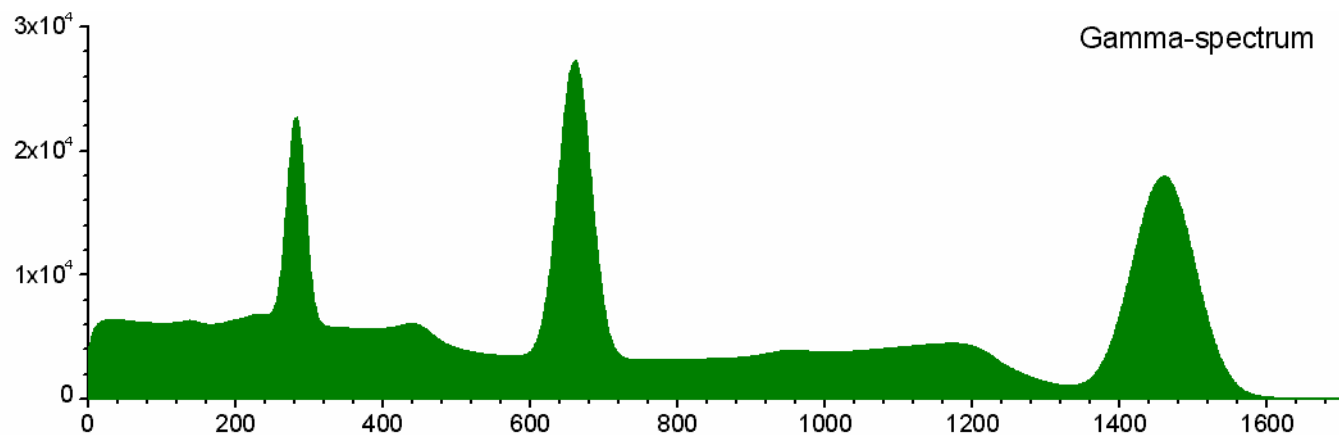
## Outline

- **GSG in basic mode**
  - Modeling approach
  - Introduction to the GSG features
  - Experimental validation of the GSG
- **GSG-PRO**
  - Additional modeling features
  - Introduction to coupled eMC-GSG simulations
  - Examples of experimental validation
- **Exercises**

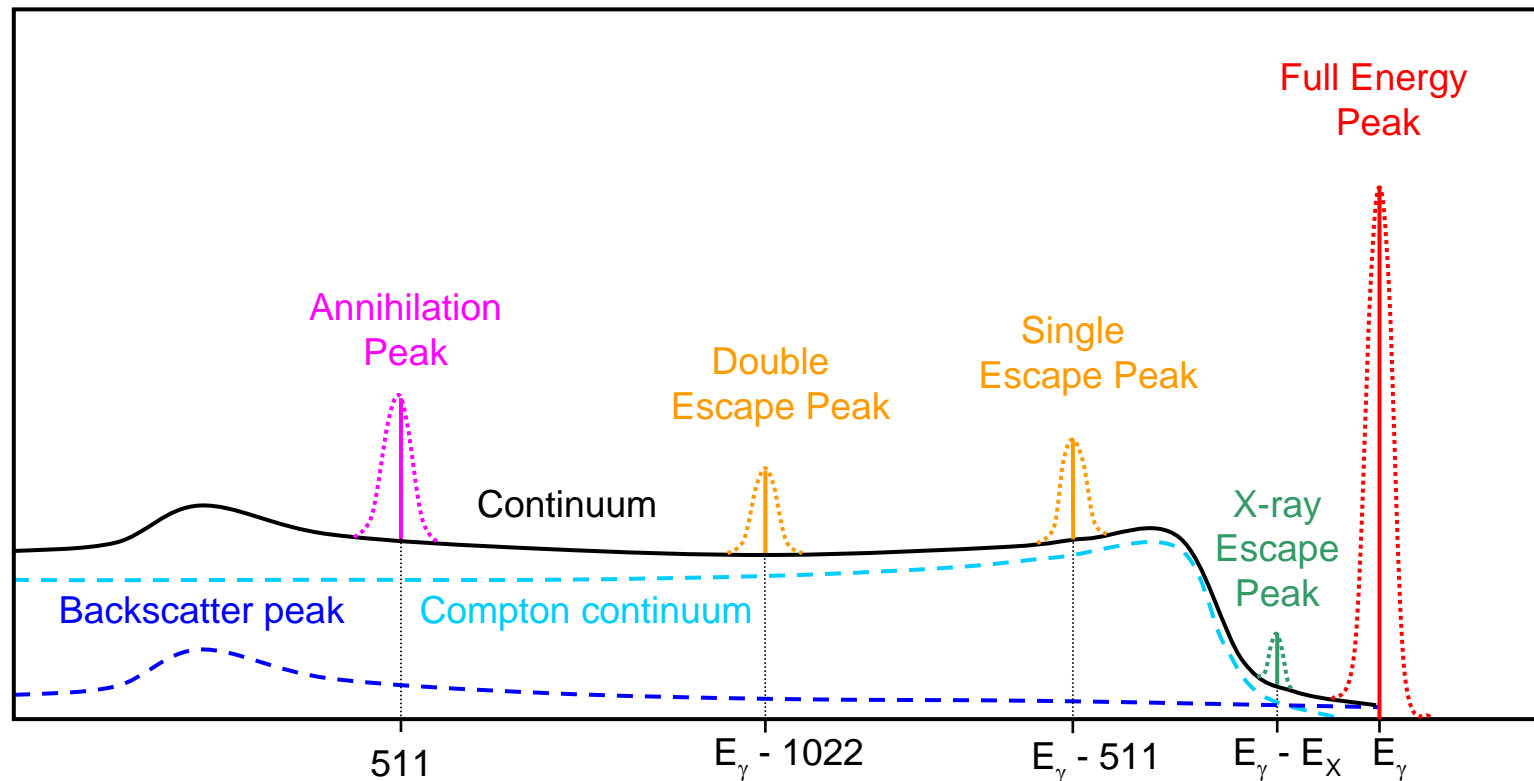
## Measurement setup model implemented:



## Spectrum modeling procedure:



- For spectrum modeling the GSG uses a comprehensive database of detector responses for gamma-ray energies from 10 keV to 10 MeV, which were obtained using extensive Monte Carlo simulations



- More details on the GSG simulation approach see in Nucleonica Wiki at [http://www.nucleonica.net/wiki/index.php/Help:Gamma\\_Spectrum\\_Generator](http://www.nucleonica.net/wiki/index.php/Help:Gamma_Spectrum_Generator)

Select an arbitrary individual nuclide or a pre-defined mixture of nuclides as a radiation source

Specify the quantity (activity, mass or number of atoms) of a nuclide or a mixture either

- at the spectrum measurement starting point of time, or
- at the moment of nuclide/mixture creation.

In the last case, the controls for specifying duration of a source "cooling" time interval become available.

The screenshot shows the Nucleonica Gamma Spectrum Generator web application. The interface is divided into several sections. At the top, there's a header with the nucleonica logo and the text "... web driven nuclear science". Below this, there are navigation links: Applications, Data, Knowledge, My Preferences, Print, Help, and New Browser. The main content area is titled "Gamma Spectrum Generator" and "27 Cobalt". It includes a small thumbnail of a gamma spectrum. Below the title, there are input fields for Element (Co), Mass (60), Quantity (Bequerel), Reference point (Nuclide creation), and "Cooling" time (sec, 0). There's also a "Nuclide Mixtures Selector" button. Below these fields, there are tabs for "Measurement setup", "Calculation results", and "Options". The "Measurement setup" tab is active, showing a diagram of a radiation source, a filter, and a detector (Nal Crystal). The diagram includes dimensions: Source to Detector distance (250.0), Crystal length (76.2), and Crystal diameter (76.2). There are buttons for "Start", "Start in background", "Save as", and "Delete". A "Show more settings" checkbox is at the bottom right of the diagram area. The status bar at the bottom says "Done".

Links to the quick start and detailed reference manuals, as well as to the GSG user's forum

Press "Start" button to start a simulation

- Choose a suitable  $\gamma$ -spectrometer from 6 pre-defined configurations, including HPGe and NaI detectors, or
- Select "Edit" to create a new spectrometer.

Tick the checkbox to get access to additional spectrometer settings

## Configuring a new spectrometer:

Dimensions can be entered in "mm", "cm" or "inch" units

The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.

Dimensions in

Source

Filter

HPGe

Crystal

250.0

Source to Detector distance

59.0

Crystal diameter

10.0

Contact diameter

45.0

Contact length

70.0

Crystal length

☒ Show more settings

	Filter:	Material	Thickness
	Filter:	Aluminum	0.2
	Input window:	Aluminum	0.5
	Crystal packaging:	Vacuum	3.0
	Inactive layer / Reflector:	Germanium	0.5

No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

Number of channels in the spectrum accumulated:

Channel-to-energy conversion factor, keV/channel:

Energy resolution (FWHM) in keV at 122 keV:

Energy resolution (FWHM) in keV at 1332 keV:

The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

## Setting up calculation options:

Nucleonica - Gamma Spectrum Generator - Windows Internet Explorer

http://localhost:1652/WebSite1/Application/Spectrum.aspx#

Nucleonica - Gamma Spectrum Generator

**Gamma Spectrum Generator**  
Natural Uranium

Actual chart: Karlsruhe

Nuclide Mixtures:  
Natural Uranium Nuclide Selector

Total activity:  
Bequerel 2.557e+004

Reference point:  
Measurement start

Measurement setup Calculation results Options

Gamma Spectrum Generator Settings:

- ☒ Display detector efficiency curves
- ☒ Consider decay transformations during cooling and counting time intervals
  - ☒ Include gamma-rays of daughter nuclides
  - 0.01 Decay Engine's accuracy factor
- ☒ Consider effects of backscatter radiation
  - 1.0 Backscatter peak normalisation factor

Efficiency Graph  
can be activated  
in the Calculation  
Results output

The backscatter  
peak simulation  
can be switched  
on/off, and its  
contribution to  
the spectrum can  
be adjusted

Decay  
calculations can  
be enabled that  
will allow  
contributions  
from decay  
products, being  
accumulated  
during source  
cooling and  
spectrum  
measurement  
time intervals



## Exploring calculation results:

Statistical number of counts

Count rate at start

Count rate at end

Theoretical number of counts

Statistical number of counts

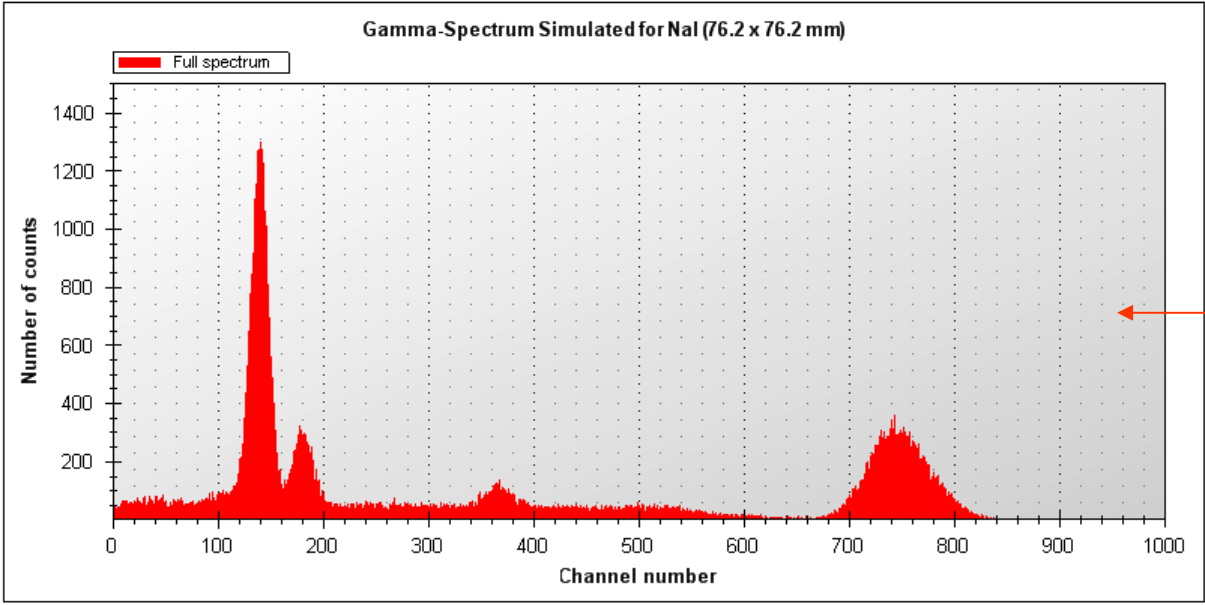
Measurement setup
Calculation results
Options

Data displayed: Statistical number of counts

View/Save results in [Text](#) or [Excel](#) format

Complete set of spectral information can be downloaded as a text or Excel spreadsheet file

**Gamma-Spectrum Simulated for NaI (76.2 x 76.2 mm)**



Update spectrum graph

Display: ☐ Energy scale ☐ Spectrum continuum ☐ Contribution of scattered photons ☐ More graph options

Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	<input type="checkbox"/>
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	<input type="checkbox"/>
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	<input type="checkbox"/>
<b>Total</b>		<b>8.92E+01</b>	<b>8.90E+01</b>	<b>8.97E+04</b>	

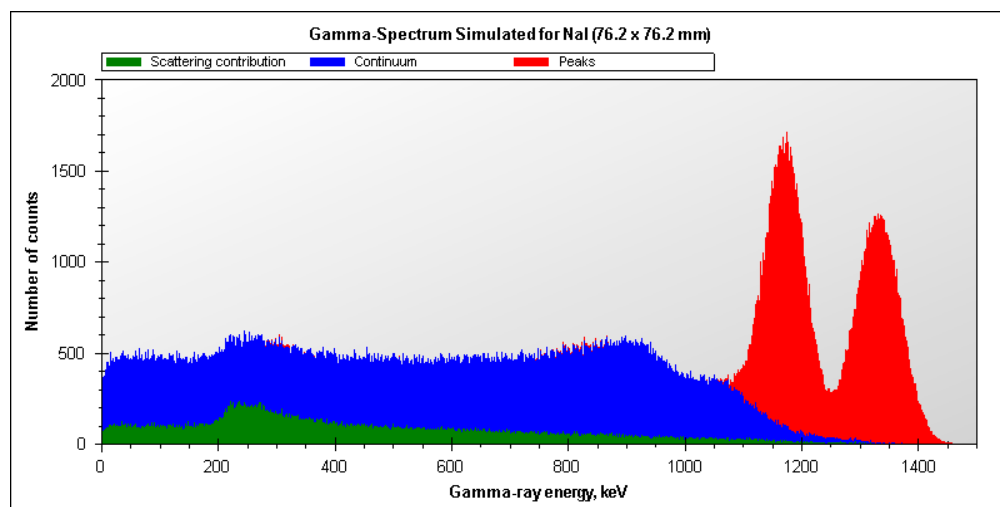
Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

Additional options allow to customize appearance of the graph to meet one's needs and requirements

Display nuclide specific contributions to the full spectrum

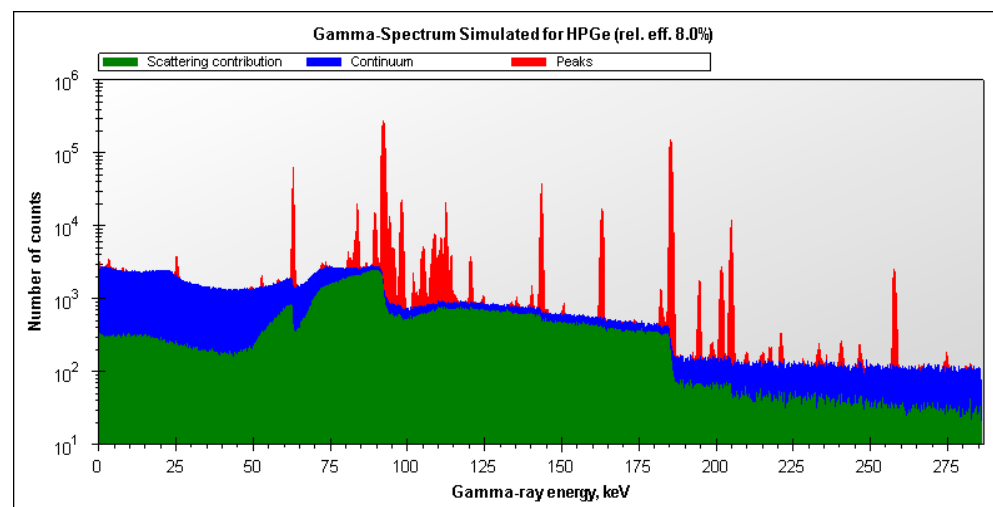
## Displaying peak and continuum contributions:

100 kBq  $^{60}\text{Co}$



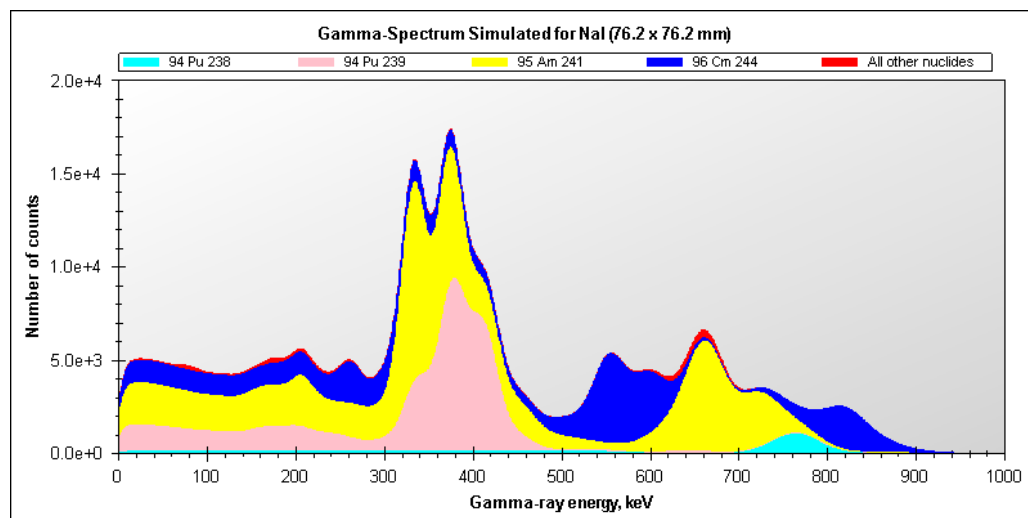
Detector - NaI (Ø3"×3")  
Source-to-detector distance - 25 cm  
Measurement time - 1000 s

1 g Nat U (2 years after separation)

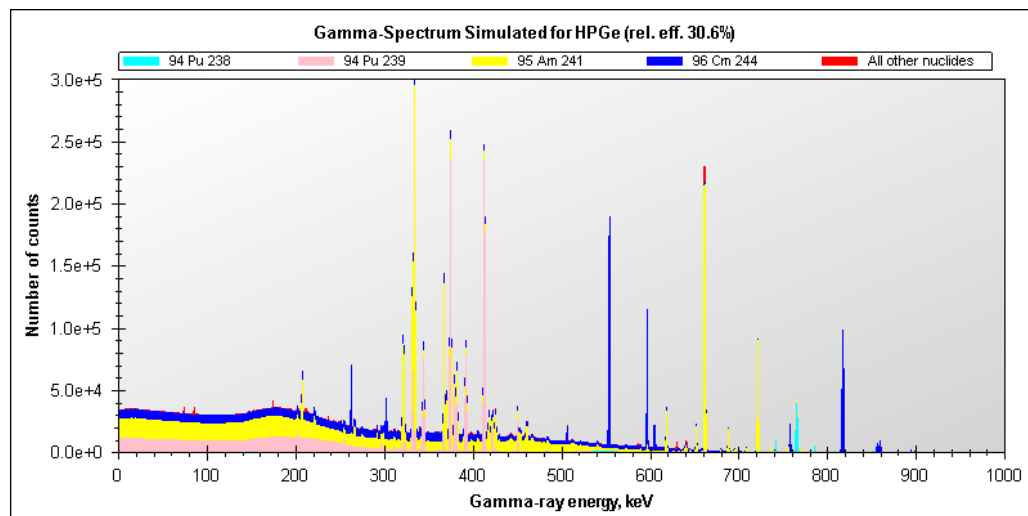


Detector – LEGe (20 mm × 2800 mm<sup>2</sup>)  
Source-to-detector distance – 25 mm  
Filter – 0.5 mm Sn  
Measurement time -  $10^5$  s

## Displaying contributions of different nuclides:



Detector – NaI (Ø3"×3")  
Source-to-detector distance – 25 cm  
Filter – 5 mm Pb  
Measurement time - 1000 s



**Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq**

Detector – BEGe (30% rel. eff.)  
Source-to-detector distance – 25 cm  
Filter – 5 mm Pb  
Measurement time - 1000 s

## Saving calculation results in Text / Excel formats:

**Calculation Parameters**

Microsoft Excel - GC-6020\_Cs137\_170mm\_Spectrum.xls

A	B	C	D	E
1	<b>Nucleonica - GAMMA SPECTRUM GENERATOR Version 1.0.0.1</b>			
2				
3	File content: Calculation Results			
4	Created: 4/17/2008 3:21:29 PM (UTC)			
5				
6	<b>SPECTROMETER:</b>			
7	Configuration name	Noname		
8	Crystal type	HPGe		
9	Crystal length	52.00	mm	
10	Crystal diameter	72.20	mm	
11	Contact length	36.00	mm	
12	Contact diameter	10.00	mm	
13	Inactive layer	0.90	mm	Germanium
14	Crystal packaging	5.00	mm	Vacuum
15	Detector input window	1.50	mm	Aluminum
16	Number of additional filters	0.00		
17	Filter No.1	0.00	mm	
18	Filter No.2	0.00		
19	Filter No.3	0.00		
20	Filter No.4	0.00		
21	Filter No.5	0.00		
22	Filter No.6	0.00		
23	FWHM at 122 keV			
24	FWHM at 1332.5 keV			
25	Number of channels			
26	Channel-to-Energy conversion			
27	Source-to-Detector distance			
28	Spectrum measurement time			
29				
30	<b>SOURCE:</b>			
31	Nuclide	56 Ba 137m		
32	Quantity	1		
33	Reference point of time			
34	Source cooling interval	30	min	
35				
36	<b>CALCULATION:</b>			
37	Consider decay transformations	Yes		
38	Include gammas of daughter nuclides	Yes		
39	Decay engine's accuracy factor	0.01		
40	Consider backscatter radiation	Yes		
41	Backscatter peak normalization factor	2		
42				

**Nuclide Specific Data**

Microsoft Excel - GC-6020\_Cs137\_170mm\_Spectrum.xls

A	B	C	D	E	F	G	H	I
1	<b>Nuclide</b>	<b>Ancestor</b>	<b>Activity, Bq</b>		<b>Number of decays</b>	<b>Count rate, cps</b>		<b>Number of counts</b>
2			<b>at start</b>	<b>at end</b>		<b>at start</b>	<b>at end</b>	<b>theor. statist.</b>
3	55 Cs 137	55 Cs 137	1.000E+00	1.000E+00	1.000E+00	5.652E-08	5.652E-08	5.652E-08 0.000E+00
4	56 Ba 137m	55 Cs 137	9.437E-01	9.395E-01	9.416E-01	7.177E-03	7.144E-03	7.160E-03 0.000E+00
5	<b>TOTAL:</b>		<b>0.000E+00</b>	<b>0.000E+00</b>	<b>0.000E+00</b>	<b>7.177E-03</b>	<b>7.144E-03</b>	<b>7.160E-03 0.000E+00</b>

Microsoft Excel - GC-6020\_Cs137\_170mm\_Spectrum.xls

File Edit View Insert Format Tools Data Windows Help

Gamma and X-ray Data

Type a question for help

A12

A B C D E F G H I J K L

Energy, keV X/G ray Emission rate, 1/s at start at end Photons emitted Peak area peak bkg Peak region counts Detection efficiency total FEP Ancestor's MDA(0), Bq

350 G 5.800E-06 5.800E-06 5.800E-06 2.715E-08 4.094E-05 7.530E-03 4.681E-03 1.441E+08

47 X 9.837E-03 9.793E-03 9.815E-03 0.000E+00 2.757E-05 0.000E+00 0.000E+00 NAN

82 X 1.951E-02 1.943E-02 1.947E-02 5.198E-07 3.363E-05 2.775E-05 2.676E-05 9.635E+08

19 X 3.600E-02 3.584E-02 3.592E-02 1.137E-06 3.301E-05 3.285E-05 3.171E-05 1.997E+08

40 X 1.310E-02 1.304E-02 1.307E-02 2.193E-06 3.211E-05 1.727E-04 1.681E-04 5.304E+07

66 G 8.500E-01 8.462E-01 8.481E-01 1.960E-03 2.144E-06 6.715E-03 2.311E-03 1.964E+03

E F

DEP Eff. Total Eff.

0.000E+00 8.505E-15

0.000E+00 1.218E-13

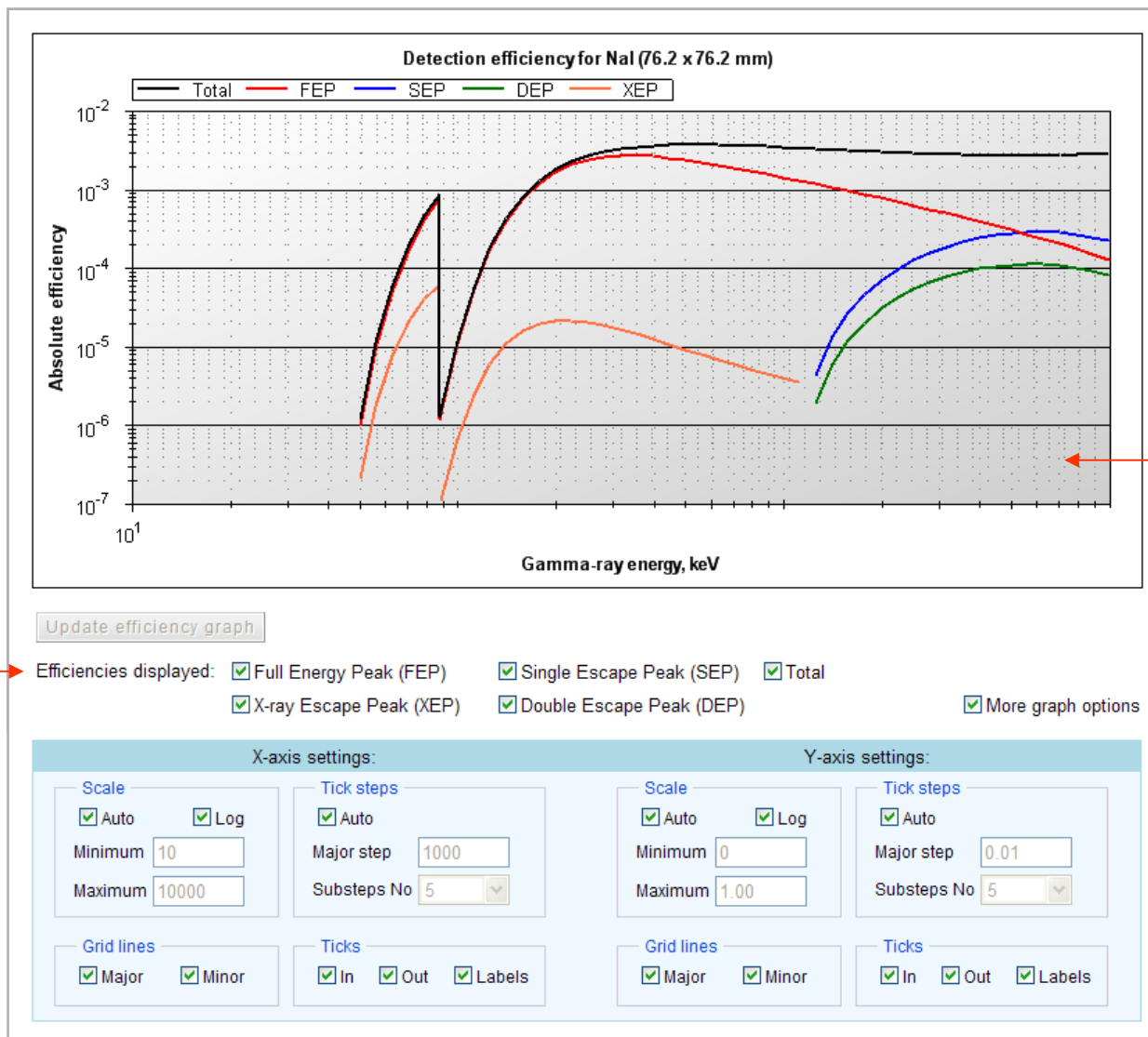
Gamma-rays / Efficiency / 56 Ba 137m / 55 Cs 137 / Full spectrum

**Gamma Spectrum**

Microsoft Excel - GC-6020\_Cs137\_170mm\_Spectrum.xls

A	B	C	D	E	F	G	H	I	J	K
1	<b>Energy, keV</b>	<b>Count rate at start, cps</b>			<b>Count rate at end, cps</b>			<b>Theoretical number of counts</b>		
2		<b>Continuum</b>	<b>Scattered</b>	<b>Total</b>	<b>Continuum</b>	<b>Scattered</b>	<b>Total</b>	<b>Continuum</b>	<b>Scattered</b>	<b>Total</b>
3	0.20	2.637E-06	8.042E-07	2.650E-06	2.625E-06	8.006E-07	2.638E-06	2.631E-06	8.024E-07	2.644E-06
4	0.60	3.185E-06	9.725E-07	3.218E-06	3.171E-06	9.681E-07	3.204E-06	3.178E-06	9.703E-07	3.211E-06
5	1.00	3.335E-06	1.019E-06	3.376E-06	3.320E-06	1.015E-06	3.360E-06	3.327E-06	1.017E-06	3.368E-06
6	1.40	3.381E-06	1.035E-06	3.394E-06	3.366E-06	1.030E-06	3.379E-06	3.373E-06	1.032E-06	3.387E-06
7	1.80	3.400E-06	1.042E-06	3.401E-06	3.385E-06	1.037E-06	3.385E-06	3.392E-06	1.039E-06	3.393E-06
8	2.20	3.411E-06	1.046E-06	3.411E-06	3.396E-06	1.042E-06	3.396E-06	3.404E-06	1.044E-06	3.404E-06
9	2.60	3.421E-06	1.050E-06	3.421E-06	3.405E-06	1.046E-06	3.405E-06	3.413E-06	1.048E-06	3.413E-06

## Plotting detection efficiencies:



Select efficiency data to be displayed on the graph

Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Additional options allow to tailor the efficiency graph to one's needs and requirements



## Experimental validation with 60% HPGe coaxial detector (INR, Kiev)

**Detector:** coaxial HPGe (Canberra)

- Relative efficiency: 61.8%
- Crystal dimensions:  $\varnothing 74 \text{ mm} \times 53 \text{ mm}$
- Rear contact:  $\varnothing 10 \text{ mm} \times 36 \text{ mm}$
- Inactive Ge: 0.7 mm
- Crystal end cap: 1.5 mm Al
- End cap to crystal gap: 5 mm
- FWHM: 1.75 keV at 1.33 MeV

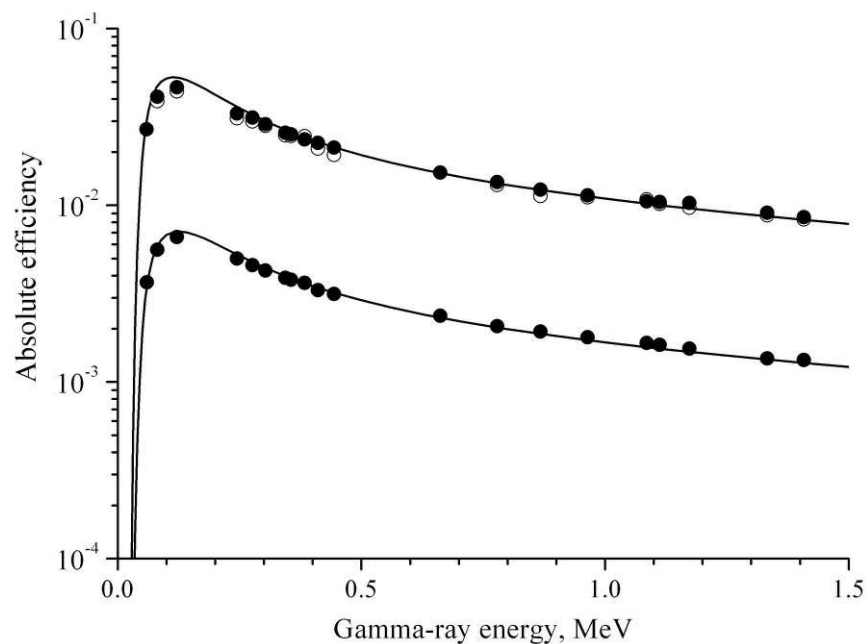
**Sources:** Thin Spectroscopic Reference Gamma-Sources (SOSGI)

- $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{152}\text{Eu}$

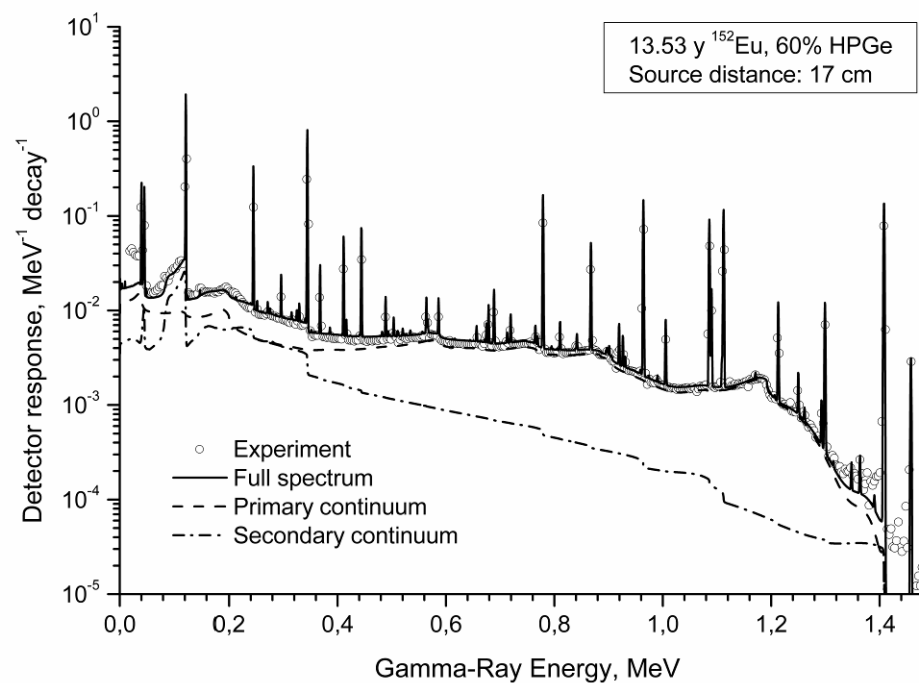
**Measurement conditions:** Center of experimental room



## Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for  $^{152}\text{Eu}$  source at 17 cm distance from the detector end cap.

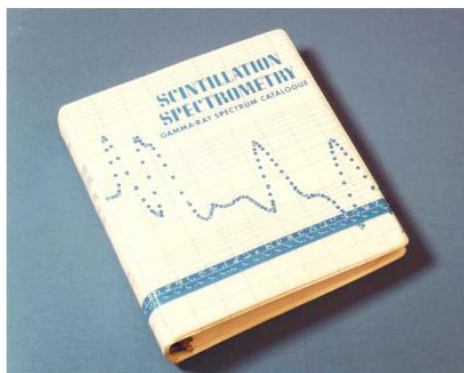
REVISED EDITION OF REPORT IDO - 16880 - 1  
ORIGINAL ISSUED: AUGUST 1964  
REV. ELECTRONIC UPDATE: FEBRUARY 1997

## SCINTILLATION SPECTROMETRY GAMMA-RAY SPECTRUM CATALOGUE

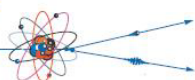
NEW VERSION OF 2ND EDITION  
COMPILATION OF GAMMA-RAY SPECTRA  
AND RELATED NUCLEAR DECAY DATA  
VOLUME 1 OF 2

BY

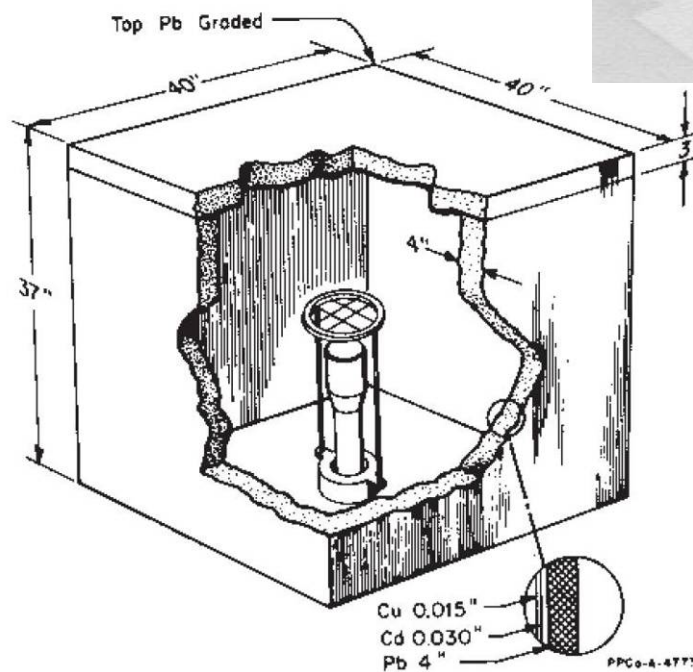
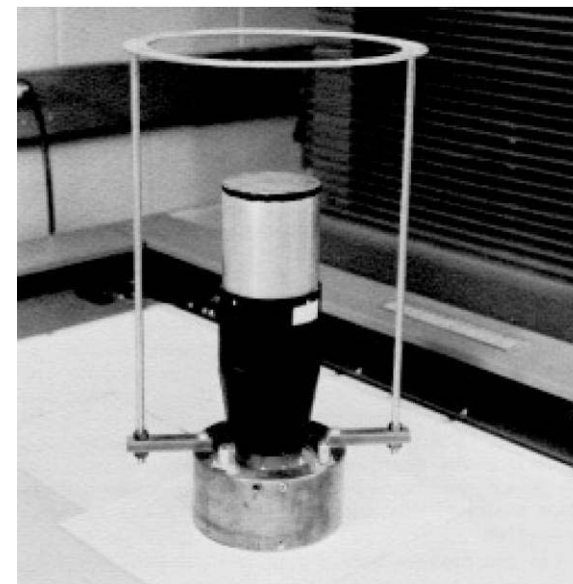
R. L. HEATH



**-RAY SPECTROMETRY CENTER**  
Idaho National Engineering & Environmental Laboratory

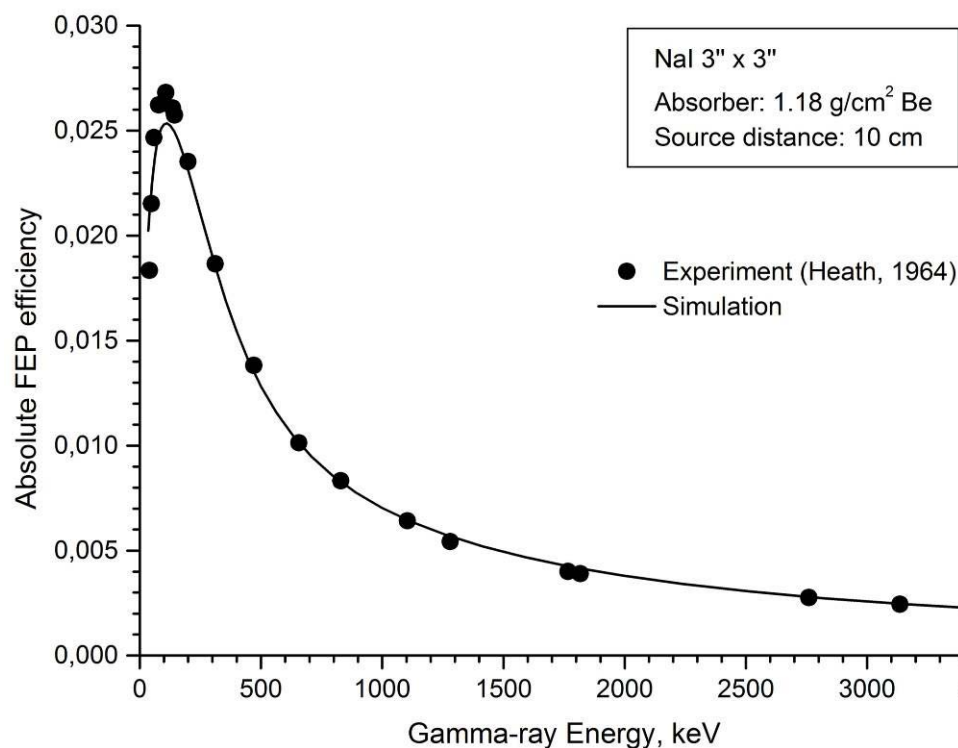


**Detector:**  
3" × 3" NaI scintillation  
detector

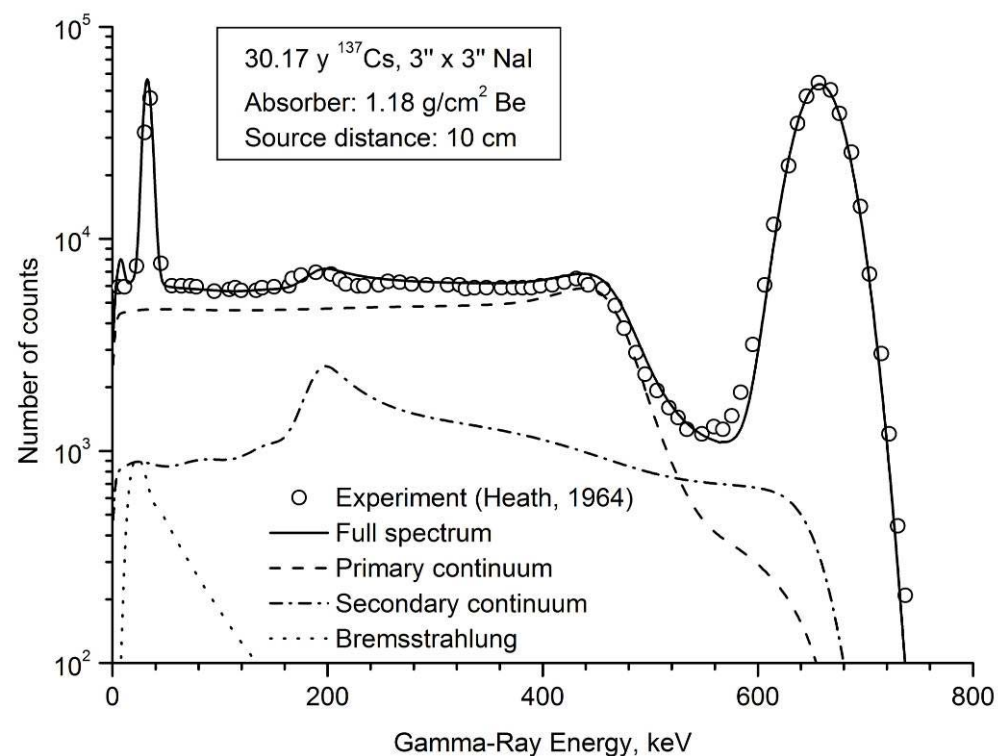




## Results of the experimental validation with 3" × 3" NaI scintillation detector

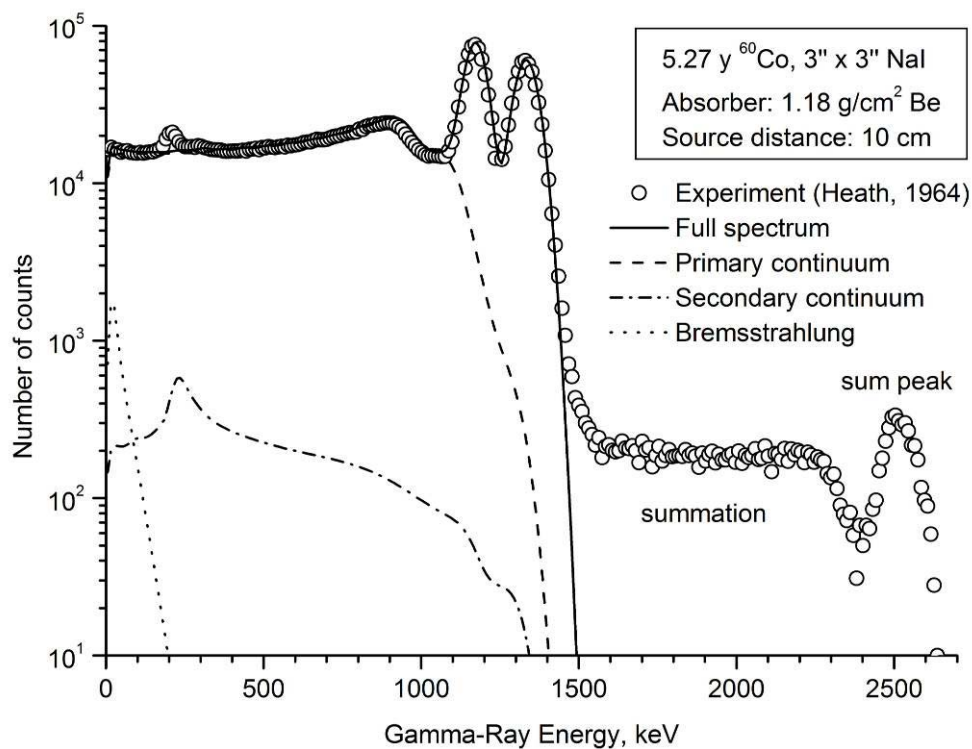


The simulated vs. experimental *FEP* efficiencies for a NaI 3" × 3" detector.

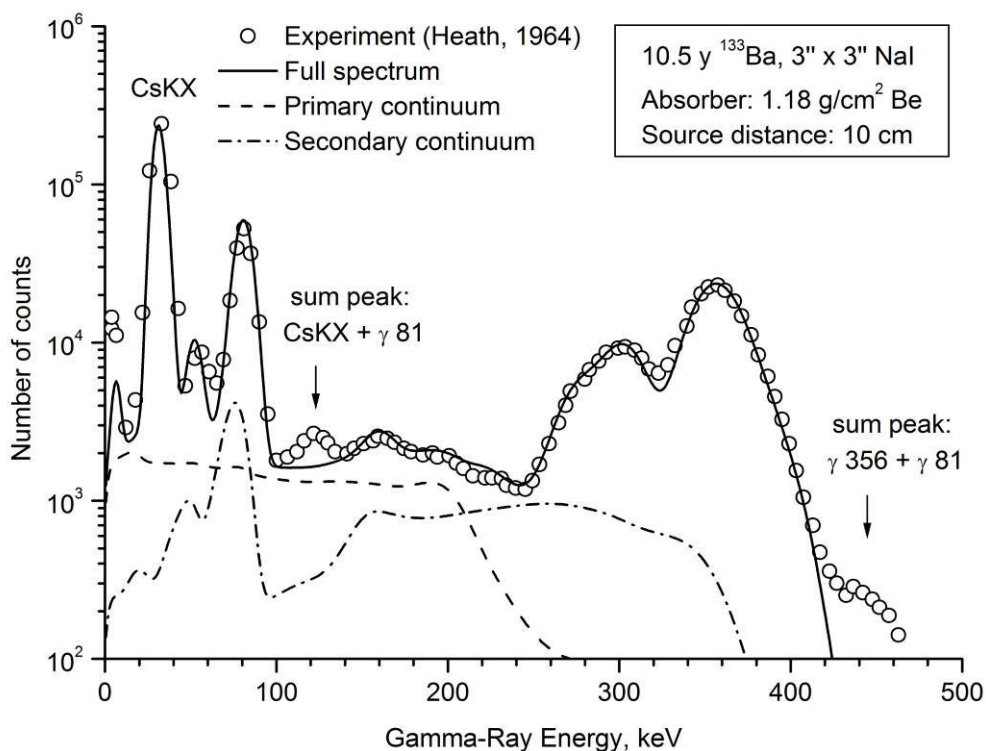


The experimental and simulated spectra for <sup>137</sup>Cs and a NaI 3" × 3" detector .

## Results of the experimental validation with 3" × 3" NaI scintillation detector

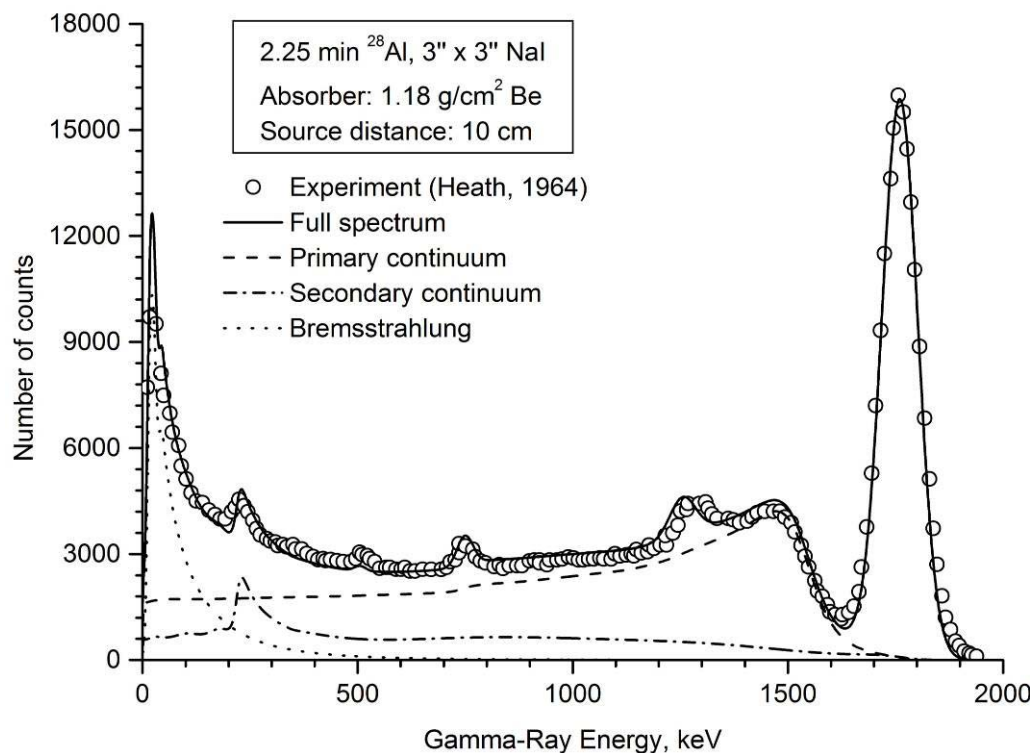


The experimental and simulated spectra for  $^{60}\text{Co}$  and a NaI 3" × 3" detector.

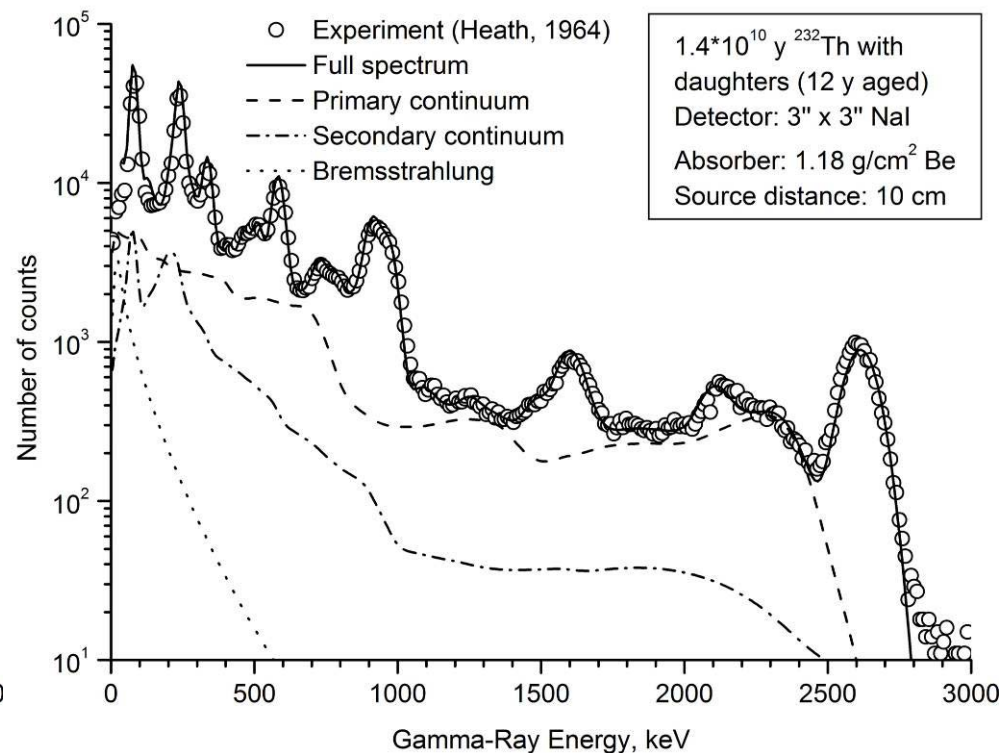


The experimental and simulated spectra for  $^{133}\text{Ba}$  and a NaI 3" × 3" detector.

## Results of the experimental validation with 3" × 3" NaI scintillation detector

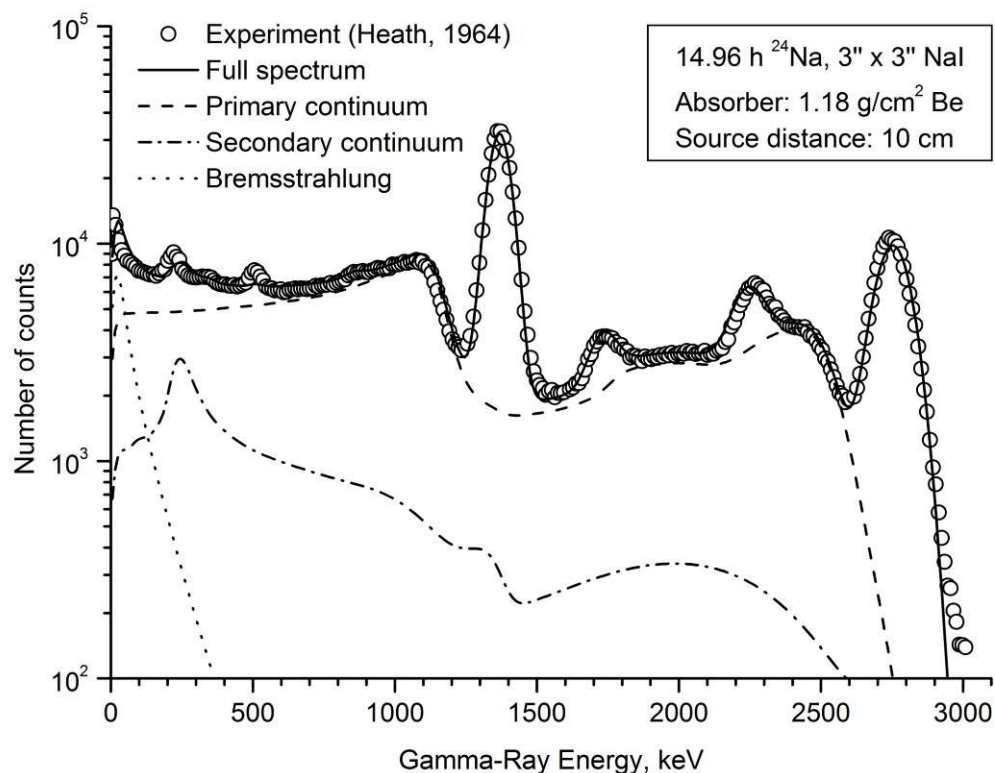


The experimental and simulated spectra for  $^{28}\text{Al}$  and a NaI 3" × 3" detector .

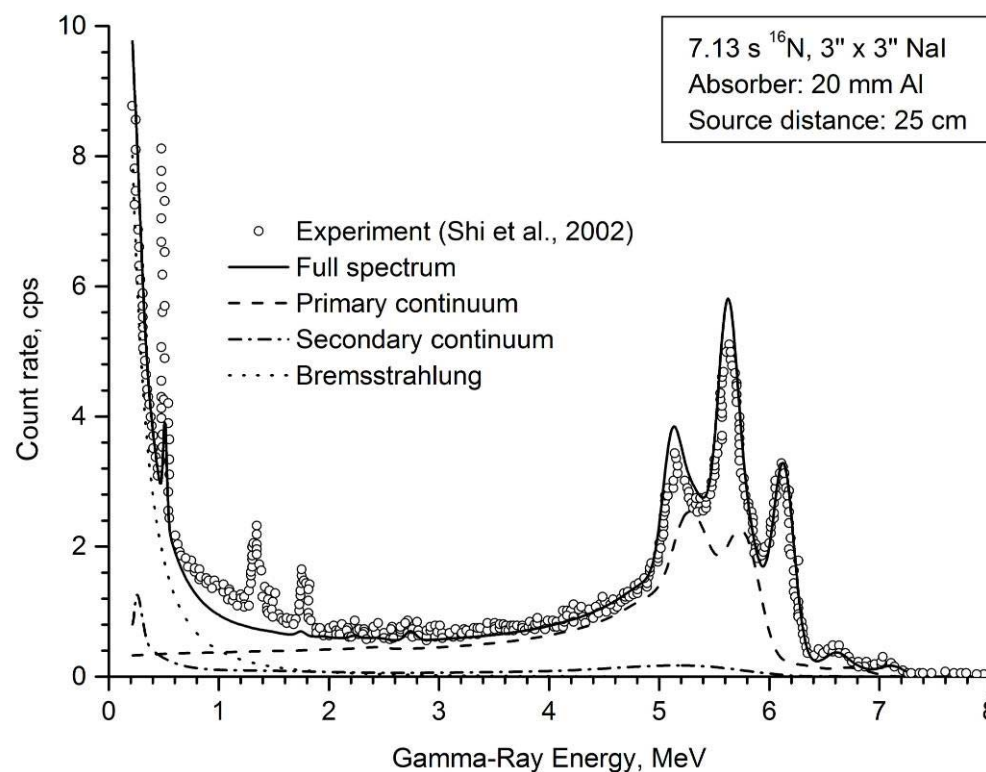


The experimental and simulated spectra for a 12 year old  $^{232}\text{Th}$  source and a NaI 3" × 3" detector.

## Results of the experimental validation with 3" × 3" NaI scintillation detector

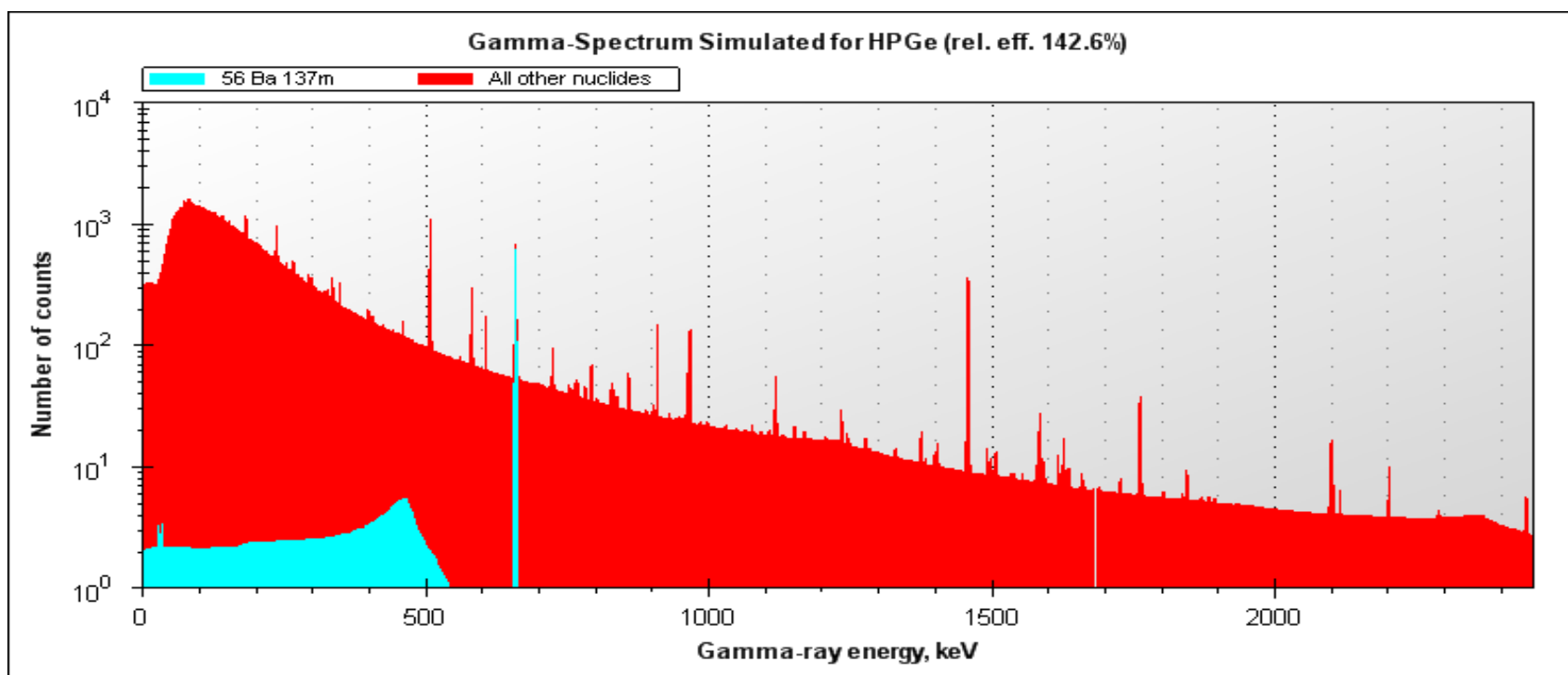


The experimental and simulated spectra for  $^{24}\text{Na}$  and a NaI 3" × 3" detector.



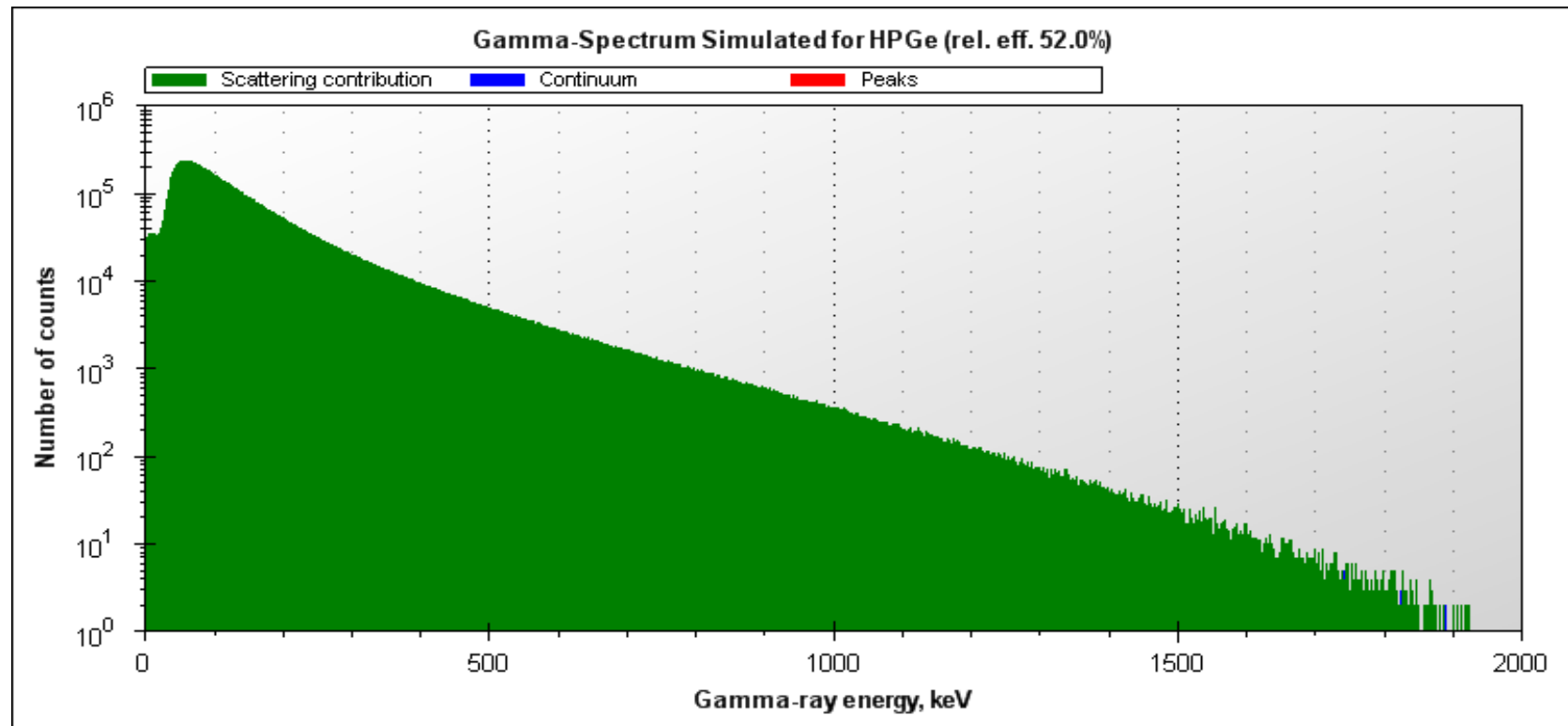
The experimental and simulated spectra for  $^{16}\text{N}$  and a NaI 3" × 3" detector.

1. Background gamma spectrum is modeled to provide more realistic spectrum shape and MDA values, especially in low-activity measurements:



- A spectrum simulated for a 10 Bq  $^{137}\text{Cs}$  source at the 10 mm distance from a 150% HPGe detector with natural background contribution included

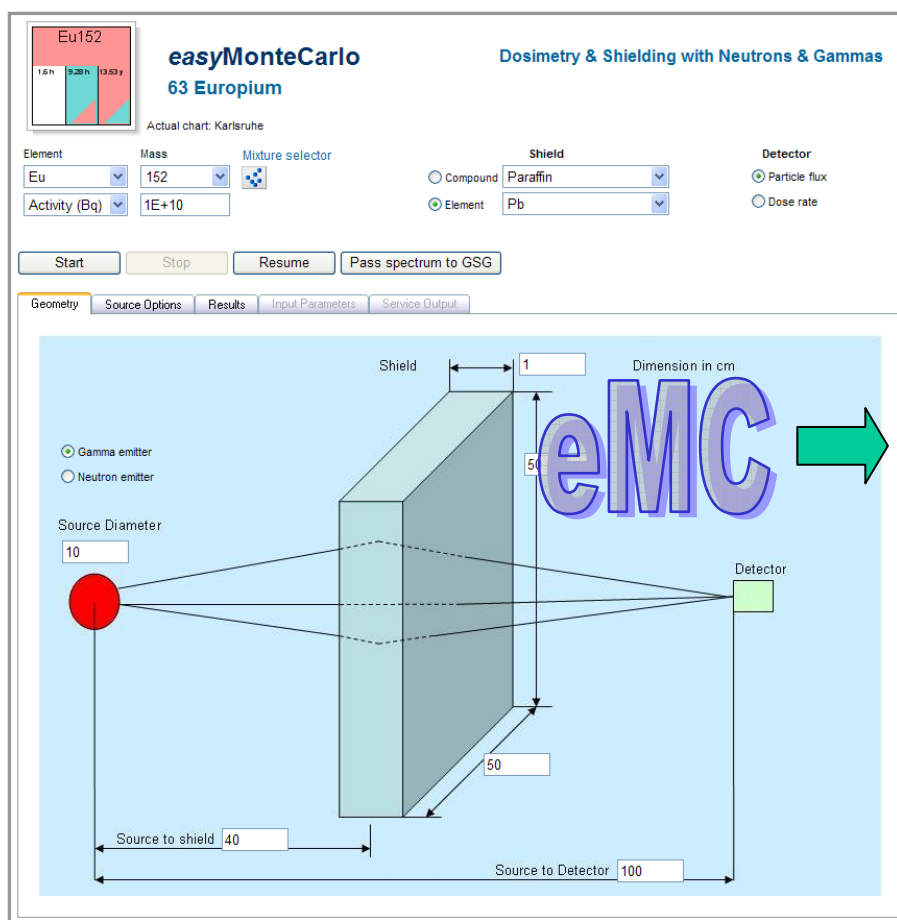
## 2. Bremsstrahlung modeling option is available for beta-emitting nuclides:



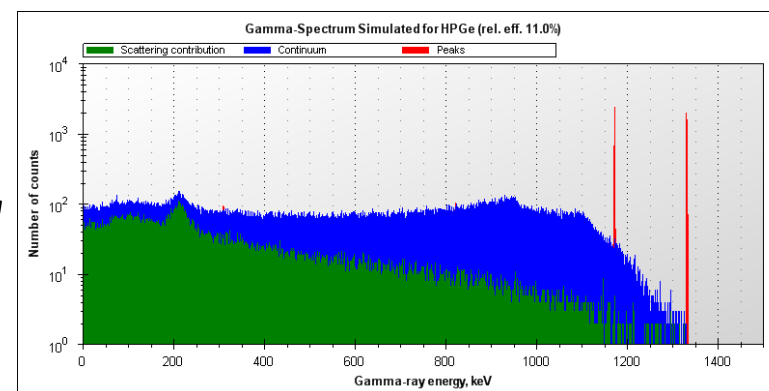
- A gamma-spectrum simulated for the 10 MBq <sup>90</sup>Sr-<sup>90</sup>Y source and a 50% HPGe coaxial detector



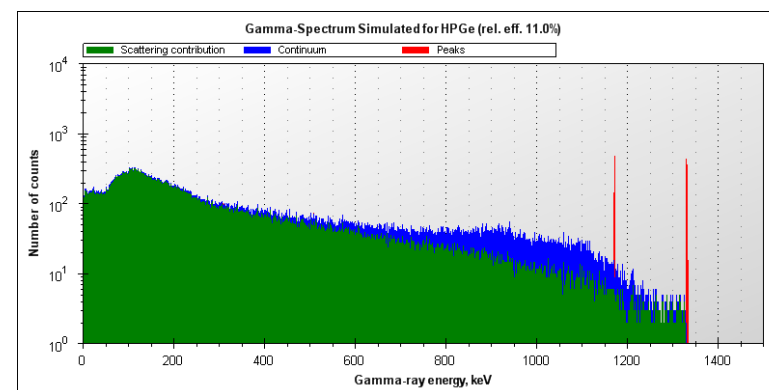
## 3. Modeling spectra from voluminous and heavily shielded sources using a coupled eMC (easy Monte Carlo) – GSG simulation approach:



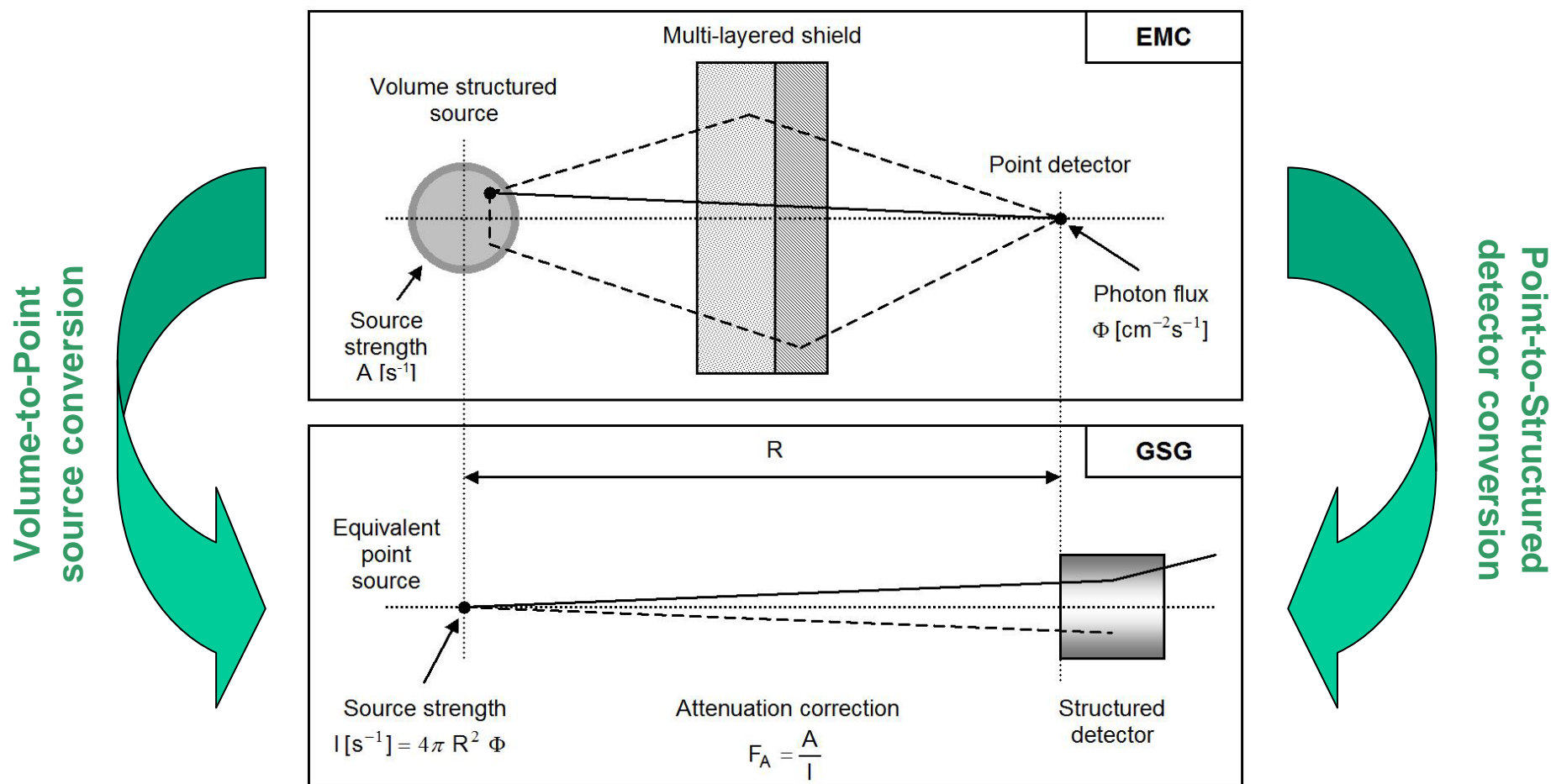
Unshielded  $^{60}\text{Co}$ :



$^{60}\text{Co}$  behind 12 cm Al shield:



## Coupled eMC / GSG calculations for voluminous & shielded sources:





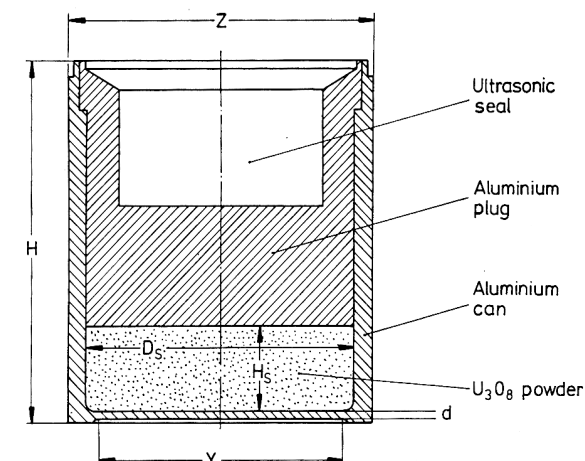


Experimental room:  $L \times W \times H = 3.3 \times 3.8 \times 3.5 \text{ m}^3$ .  
 Shields ( $20 \times 20 \text{ cm}^2$ ): Pb (2 cm) and Al (3 cm, 12 cm).  
 Detector: 10% Ortec Detective, HPGe  $\varnothing 50 \times 30 \text{ mm}$ .  
 Shield to detector: 10 cm.  
 Source to shield: 0 cm.  
 Unshielded source: at 10 cm distance.

## CBNM-446 Uranium:

Separation date: 1979  
 $\text{U}_3\text{O}_8$ , 200 g,  $3.3 \text{ g/cm}^3$   
 Capsule:  $\varnothing 8 \times 9 \text{ cm}$   
 Sample:  $\varnothing 7 \times 1.58 \text{ cm}$   
 Al window: 0.2 cm

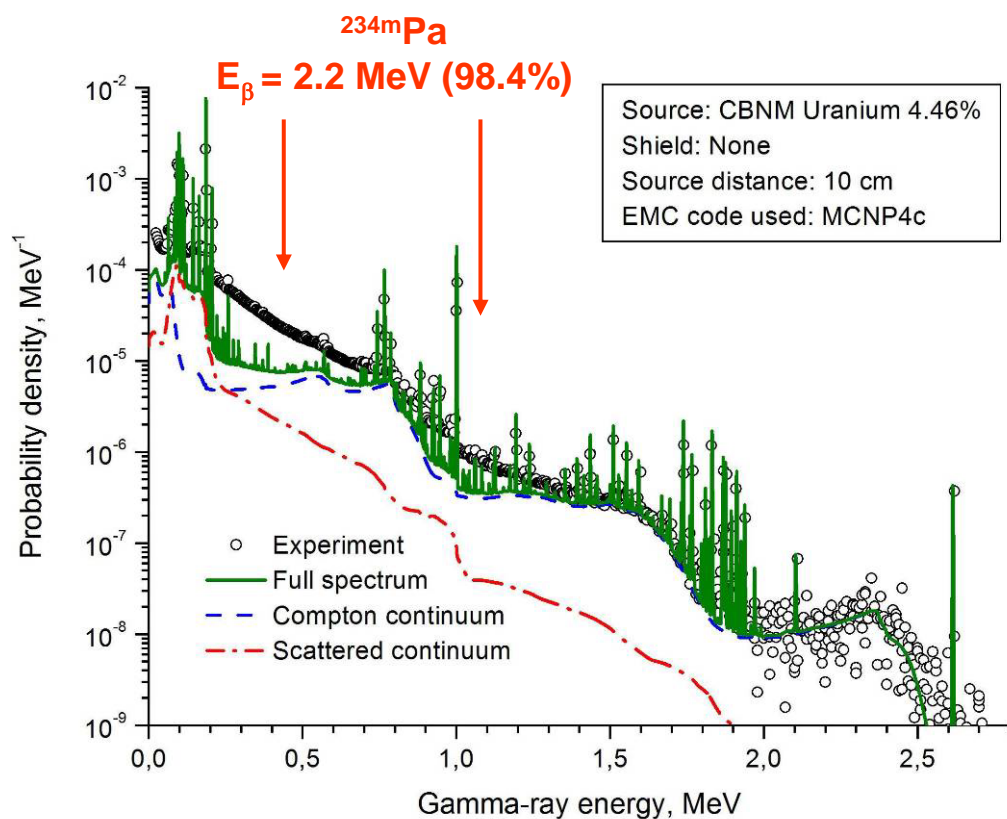
$^{232}\text{U}$  – 4.1 ppt  
 $^{234}\text{U}$  – 0.0359 wt %  
 $^{235}\text{U}$  – 4.4623 wt %  
 $^{236}\text{U}$  – 0.0068 wt %  
 $^{238}\text{U}$  – 95.495 wt %



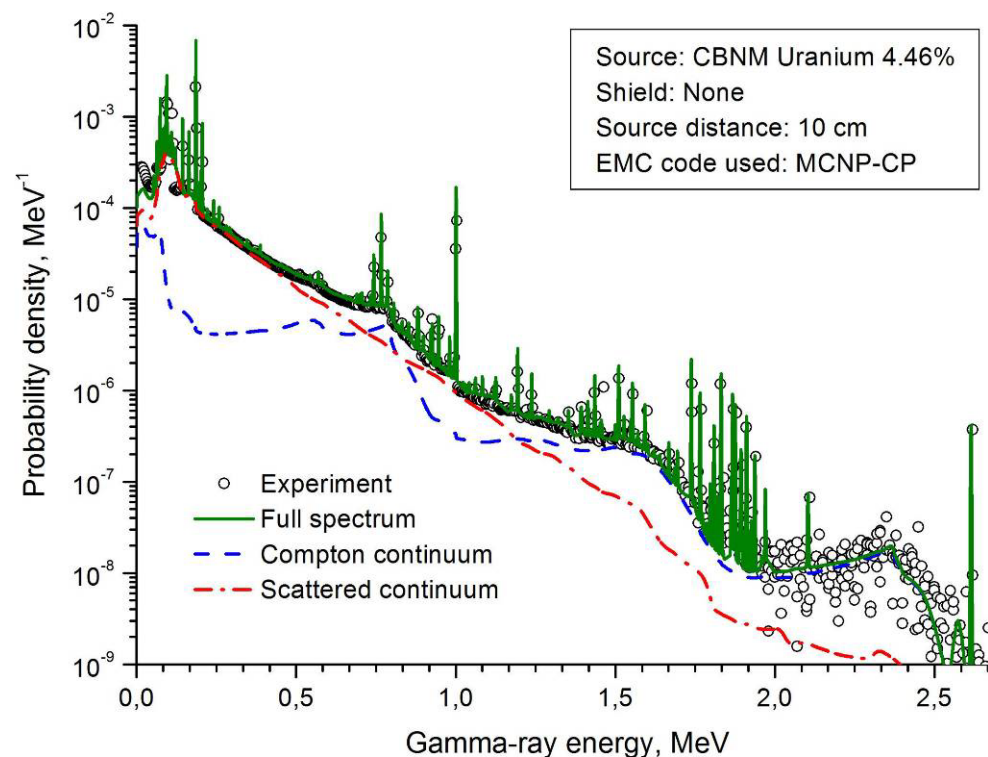
Nuclide	Activity	Nuclide	Activity
$^{234}\text{U}$	14.1 MBq	$^{219}\text{Rn}$	128 Bq
$^{238}\text{U}$	2.02 MBq	$^{211}\text{Pb}$	128 Bq
$^{234\text{m}}\text{Pa}$	2.02 MBq	$^{211}\text{Bi}$	128 Bq
$^{234}\text{Pa}$	3.03 kBq	$^{212}\text{Pb}$	438 Bq
$^{234}\text{Th}$	2.02 MBq	$^{212}\text{Bi}$	438 Bq
$^{235}\text{U}$	607 kBq	$^{224}\text{Ra}$	438 Bq
$^{231}\text{Th}$	607 kBq	$^{208}\text{Tl}$	157 Bq
$^{231}\text{Pa}$	372 kBq	<b>Total</b>	<b>21.4 MBq</b>

## Unshielded CBNM-446

### Without bremsstrahlung

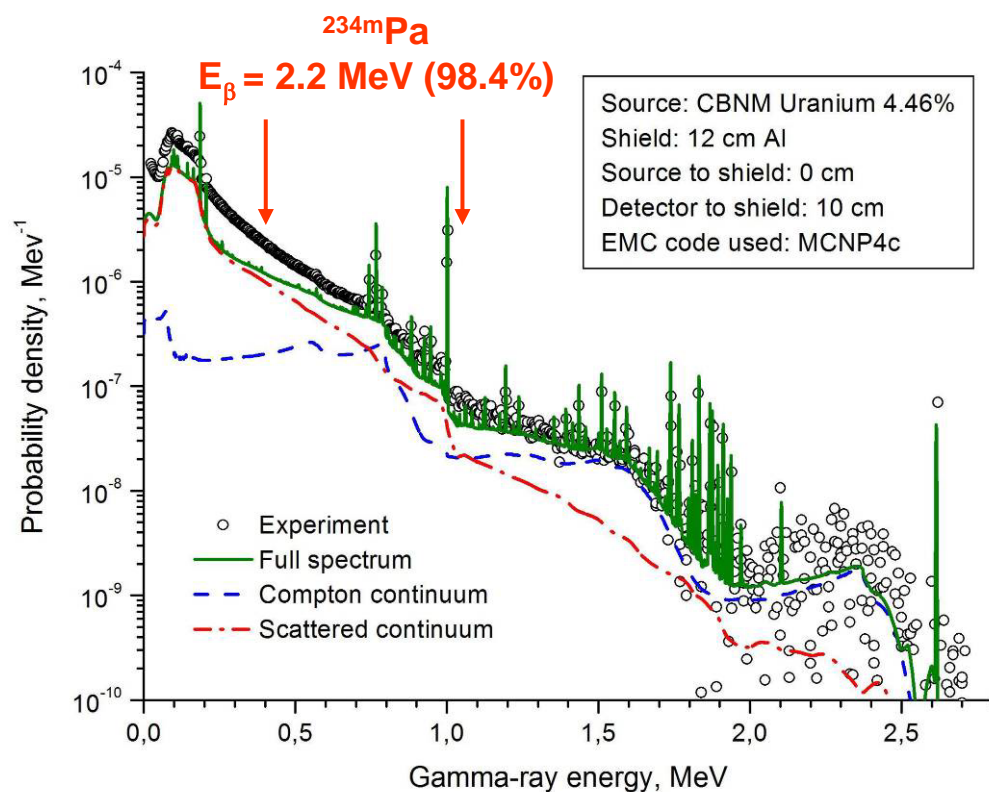


### With bremsstrahlung

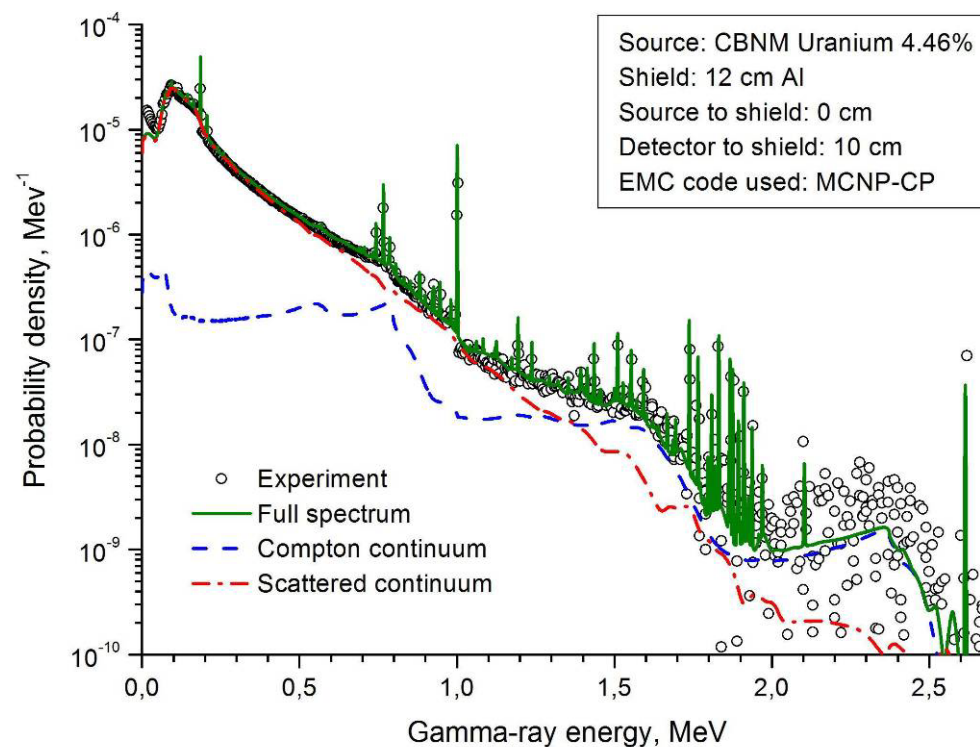


## CBNM-446 shielded with 12 cm Al

### Without bremsstrahlung



### With bremsstrahlung



Thanks !

